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New Supernova Candidates from SDSS-DR7 of Spectral Survey ^{*}

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Abstract The letter presents 25 discovered supernova candidates from SDSS-DR7 with our dedicated method, called Sample Decrease, and 10 of them were confirmed by other research groups, and listed in this letter. Another 15 are first discovered including 14 type Ia and one type II based on Supernova Identification (SNID) analysis. The results proved that our method is reliable, and the description of the method and some detailed spectra analysis procedures were also presented in this letter.

1 INTRODUCTION

Supernovae (SNe) are generally discovered by repeat imaging of the same region of sky every other night, and measuring light curves for objects in the area. The SDSS Supernova Survey was one of three surveys (along with the Legacy and SEGUE surveys) of SDSS-II, a 3-year extension of the original SDSS that operated from July 2005 to July 2008. Besides the imaging survey, the spectral survey of SDSS also gathers large amount of spectroscopy of galaxies. These spectra are basis of many astronomical research. As a byproduct, SNe in their host galaxies are possible to be detected spectroscopically Madgwick et al. (2003), since a SN spectrum might have obvious broad peaks and troughs that modulate the spectrum of its host galaxy. By the rate of SNe detection computed in Madgwick et al. (2003), there are ~ 200 Type Ia SNe detection of $\sim 10^6$ galaxy spectra in SDSS-DR7 (Abazajian et al. 2008). Madgwick et al. (2007) have detected 19 type Ia SNe from $\sim 10^5$ galaxy spectra in SDSS-DR1 (Abazajian et al. 2003) through the spectroscopic approach.

In this Letter, we reported the 14 Type Ia SNe and 1 Type II SN which are detected through spectroscopic approach in SDSS-DR7. Our method is some different with Madgwick et al. (2003), and is described in detail in §2, the detecting results are described in §3, and conclusion and future possibilities are summarized in §4.

2 METHOD

The spectroscopic approach mentioned by Madgwick et al. (2003) needs to perform galaxy subtraction and match with all templates for each spectrum. To simplify the procedure in a large number of spectra dataset,

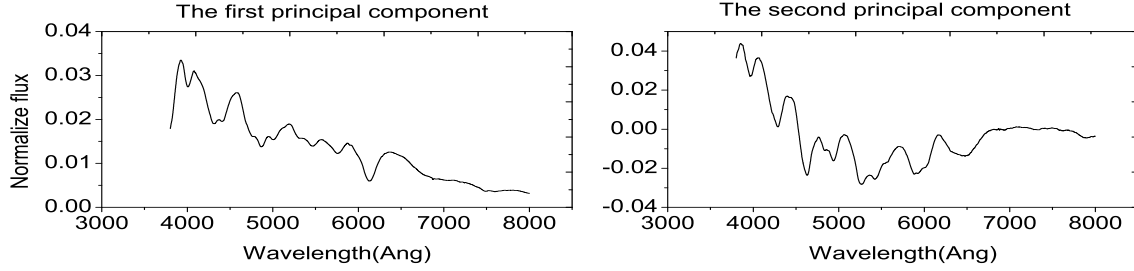


Fig. 1 The First and Second Principal Components of Ia Supernova Templates

we present a concept of “Sample Decrease”, namely before confirming SNe by template matching, the most of galaxy spectra in the dataset without obvious SN features are excluded, only those possible candidates are kept to complete the template matching.

2.1 Sample decrease

The host-galaxy spectra with SN are much more sparse than galaxy spectra without SN, so we can remove the most of them using outlier detection method. The process could be divided into two phases, the first phase is SN statistic eigen representation of each galaxy spectrum, and the second phase is outlier detection. Here, Ia-normal templates in the Peter Nugents’ SN Spectral Templates library(Nugent P. 1997) are used as our templates, which include 6th~40th templates of all 90 templates. The reasons of such template selection are that the SN characters of them are obvious and easy to detect. Linear interpolation are performed to each of these 35 SN templates to wavelength range 3801~8000Å firstly, then these 35 spectra are transformed by Principal Component Analysis (PCA) to obtain the 12 eigen spectra (eigenvectors), which span an eigen-subspace of Type Ia SN. The projection of one normalized galaxy spectrum on these space is a 12-dimension vector, and it is called a SN statistic eigen-representation of this galaxy spectrum. The first two dimension eigenspectrum (Principal component) are shown in Figure 1.

Markus M. (2000) has presented the conception of Local Outlier Factor(LOF) used for outlier detection, which can be applied to describe the singularity of galaxy spectra with SN component in all galaxy spectra. Thus, the outlier might be spectra of SNe plus their host galaxies. The definitions related to LOF are described as follows:

Definition 1: (k – distance of an object p). For any positive integer k , the k -distance of object p , denoted as k – distance(p), is defined as the distance $d(p, o)$ between p and an object $o \in D$ such that:

- (i) For at least k objects $o' \in D \setminus p$, it holds that $d(p, o') \leq d(p, o)$
- (ii) For at most $k-1$ objects $o' \in D \setminus p$, it holds that $d(p, o') < d(p, o)$.

Definition 2:(k – distance neighborhood of an object p). Given the k – distance of p , the k – distance neighborhood of p contains every object whose distance from p is not greater than the k – distance, i.e. $N_{k\text{-distance}(p)}(p) = \{q \in D \setminus p \mid d(p, q) \leq k\text{-distance}(p)\}$. These objects q are called the k – nearest neighbors of p . Simplify the notation to use $N_k(p)$ as a shorthand for $N_{k\text{-distance}(p)}(p)$.

Definition 3: (reachability distance of an object p w.r.t object o). Let $k \in \mathbb{Z}^+$, the reachability distance of object p with respect to object o is defined as $reachdist_k(p, o) = \max\{k\text{-distance}(o), d(p, o)\}$.

$$lrd_k(p) = 1 / \frac{\sum_{o \in N_k(p)} reachdist_k(p, o)}{|N_k(p)|} \quad (1)$$

$$LOF_k(p) = \frac{\sum_{o \in N_k(p)} \frac{lrd_k(o)}{lrd_k(p)}}{|N_k(p)|} \quad (2)$$

Using the above k -LOF definition, we can design the procedures of data reduction:

- (i) calculate the k - *distance* of each sample in D ;
- (ii) ascertain the k - *distance* neighborhood of each object $p \in D$;
- (iii) calculate the local reachability density of each object $p \in D$ using formula (1);
- (iv) calculate the k -local outlier factor of each object $p \in D$ using formula (2);
- (v) array all of the objects in D according to their k -LOF in descending order, and keep the objects which have higher k -LOF as the range of candidates, here we keep 1 \sim 2 percent of all samples.

2.2 Cross-correlation template matching based on SNID

After sample decrease in SDSS-DR7, the number of remainder is 2945. Template matching should be completed for this relative small dataset. Blondin et al. (2007) presented an interactive cross-correlation method named SNID to identify SNe, and get the redshift, age, and type of each SN, since all template spectra are at zero redshift, and type and age of each template is known. We simplify the SNID procedure into first four steps as follow and make it running automatically, then the 5th step is to run SNID pipeline to confirm selected samples with high probability to be SN:

- (i) Bin each spectrum on a logarithmic wavelength axis.
 - (ii) Continuum removal and spectra normalizing.
 - (iii) Smooth the spectra using mean filter, remove strong lines in each spectrum.
 - (iv) Matching by cross-correlation, details can be found in Blondin et al. (2007) and Tonry et al. (1979).
 - (v) Each candidate with high confidence as a SN should be checked interactively through SNID pipeline.
- An example of a spectrum which is addressed according to the former steps is shown in Figure 2.

3 RESULTS

We applied our method to all fields of SDSS DR7 (survey plate number 0266 \sim 2974), excluding the spectra with low signal to noise ratio (S/N) and with uncertainty of high redshift. The selection criteria are: $S/N > 10$ (all in g,r,i band), $z < 0.25$, and with the spectral type “galaxy”. The total number of galaxy spectra is 294843, in which we performed the sample decrease procedure. First step is to de-redshift for all galaxy spectra, like figure 2 shows. Secondly, strong lines were removed in each spectrum using narrow scaled wavelet filter, just to keep broad peaks and troughs such as SiII absorption at 6150Å, which is one of main characters of Ia SN spectrum. A spectrum that strong lines are removed is shown in the left bottom panel in Figure 2. After pre-processing, we calculated SN statistical representations for all spectra, i.e. projected each normalized spectrum on the eigen-subspace. Then, we compute and sort the LOF of each sample, and prune 99% samples with low LOFs in DR7 galaxy dataset. Finally, we obtained a total of 2945 spectra from the all 294843 spectra.

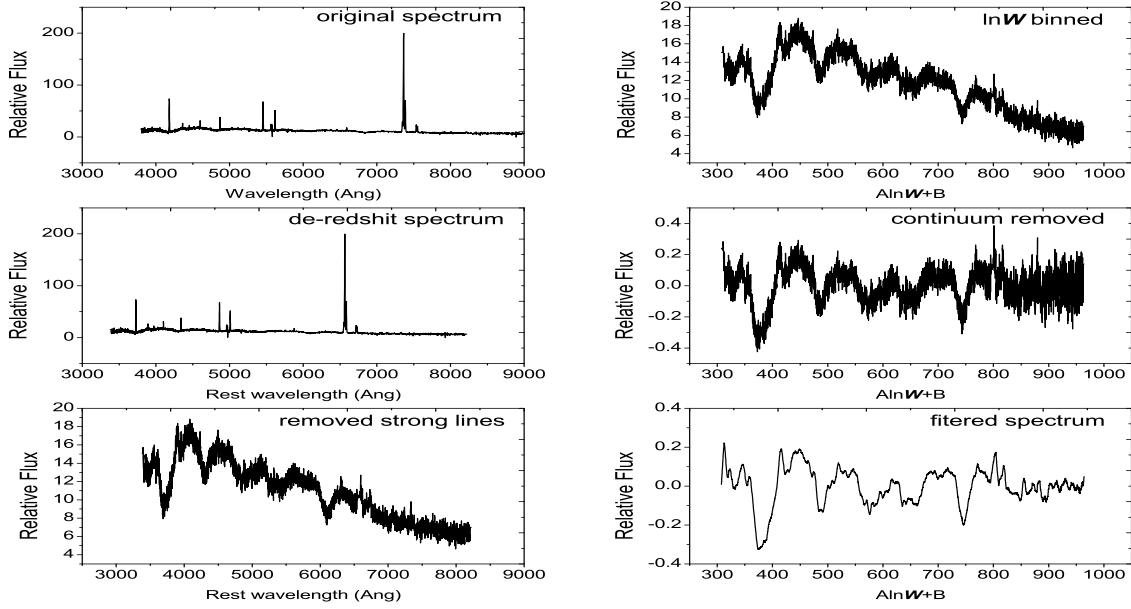


Fig.2 An example of SN spectrum. The top left shows original spectrum, the middle left is the corresponding spectrum which has been de-redshift, and the left bottom shows the result that strong lines are removed. The binned spectrum, the continuum divided spectrum and the smoothed spectrum are shown in the right three panels respectively.

Table 1 The recorded SN+host spectra that we discovered.

SDSS Name	IAU name	Date	z	Age(days)	Type	SDSS r-mag
SDSS J101800.47-000157.9	Sn 2000fx	2000-12-01	0.065	16-18	Ia-pec	17.98
SDSS J080312.61+473649.7	Sn 2000fy	2000-12-06	0.117	2.5-3.5	Ia-norm	17.93
SDSS J011835.83+144100.5	Sn 2000fz	2000-12-15	0.054	6.3-6.8	Ia-norm	16.73
SDSS J092229.14+575429.3	Sn 2001kj	2001-01-02	0.063	10-11	Ia-norm	17.79
SDSS J095153.07+010605.7	Sn 2001kp	2001-03-21	0.063	-3 to -2	Ia-pec	17.58
SDSS J095915.75+005802.3	Sn 2001kr	2001-03-26	0.086	9.4	Ia-csm	18.15
SDSS J093749.92+101138.0	Sn 2003ly	2003-12-17	0.095	17.00	Ia-norm	18.46
SDSS J095948.15+112825.3	Sn 2004ar	2004-02-20	0.064	9.80	Ia-norm	18.04
SDSS J132834.01+415108.2	Sn 2004co	2004-04-17	0.029	8.1	Ia-norm	15.82
SDSS J154024.75+325157.2	Sn 2004cp	2004-05-24	0.053	28.5	Ia-norm	17.50

calculate the similarities between a spectrum and each template, and sort them in descending order. By comparing all similarities in all template, only 65 spectra were left to be identified. Finally, we confirmed 25 spectra of them as SN through SNID. Among these 25 spectra, 5 of them have been discovered by Madgwick et al. (2003)(see top 5 rows in table 1), the other 5 spectra have been recorded elsewhere (see bottom 5 rows in table 1). The remainder of them have not been recorded, moreover, the 15 spectra are shown in Figure 3 and the parameters of them are listed in table 2.

4 CONCLUSION

A novel spectroscopic analysis of the ~ 300000 galaxy spectra in the SDSS-DR7 has resulted in the definite

Table 2 The new discovered SN+host spectra.

SDSS Name	Another name	Date	z	Age(days)	Type	SDSS r-mag
SDSS J074734.48+272647.4	anon	2002-12-10	0.061	41.6	Ia-91bg	17.45
SDSS J074933.17+275729.4	anon	2002-12-10	0.131	-5	Ia-norm	18.42
SDSS J112900.54+484359.2	anon	2003-01-03	0.085	-3.4	Ia-norm	18.01
SDSS J081647.02+251731.6	anon	2003-03-11	0.158	-8.6	Ia-norm	18.11
SDSS J160132.55+265915.1	anon	2003-07-02	0.071	-2	Ia-norm	16.64
SDSS J083909.66+072431.6	2MASX J08390967+0724320	2003-11-21	0.042	23.7	Ia-91T	17.29
SDSS J113913.53+150215.7	anon	2005-01-16	0.022	34.1	IIP	18.36
SDSS J104440.53+303803.3	anon	2005-02-28	0.077	4.3	Ia-norm	18.09
SDSS J160116.52+174603.9	MCG+03-41-035	2005-07-05	0.040	16.1	Ia-norm	16.46
SDSS J162423.71+154036.2	anon	2005-07-07	0.097	0.30	Ia-91T	17.85
SDSS J114438.44+295323.7	anon	2006-03-03	0.075	19.1	Ia-norm	17.94
SDSS J084943.93+121755.3	NGC 2682	2006-03-21	0.053	28.5	Ia-norm	18.39
SDSS J105710.63+092403.4	anon	2008-02-02	0.086	9.4	Ia-csm	18.12
SDSS J132301.40+243023.6	NGP9 F380-0370514	2008-02-28	0.088	0.3	Ia-norm	17.43
SDSS J150531.71+175904.7	2MASX J15053172+1759051	2008-03-31	0.033	14.1	Ia-norm	16.23

first is that reduced samples were fixed to 1% of all samples to keep high reliability, and some SNe would be lost. The second is that only half of Nugent's SN templates with obvious SN characters were adapted in this method. The last is that there is still a problem of host galaxy subtraction, and we have to give up searching those faint SNe. In this method, only small samples are matched with templates, which improved search efficiency.

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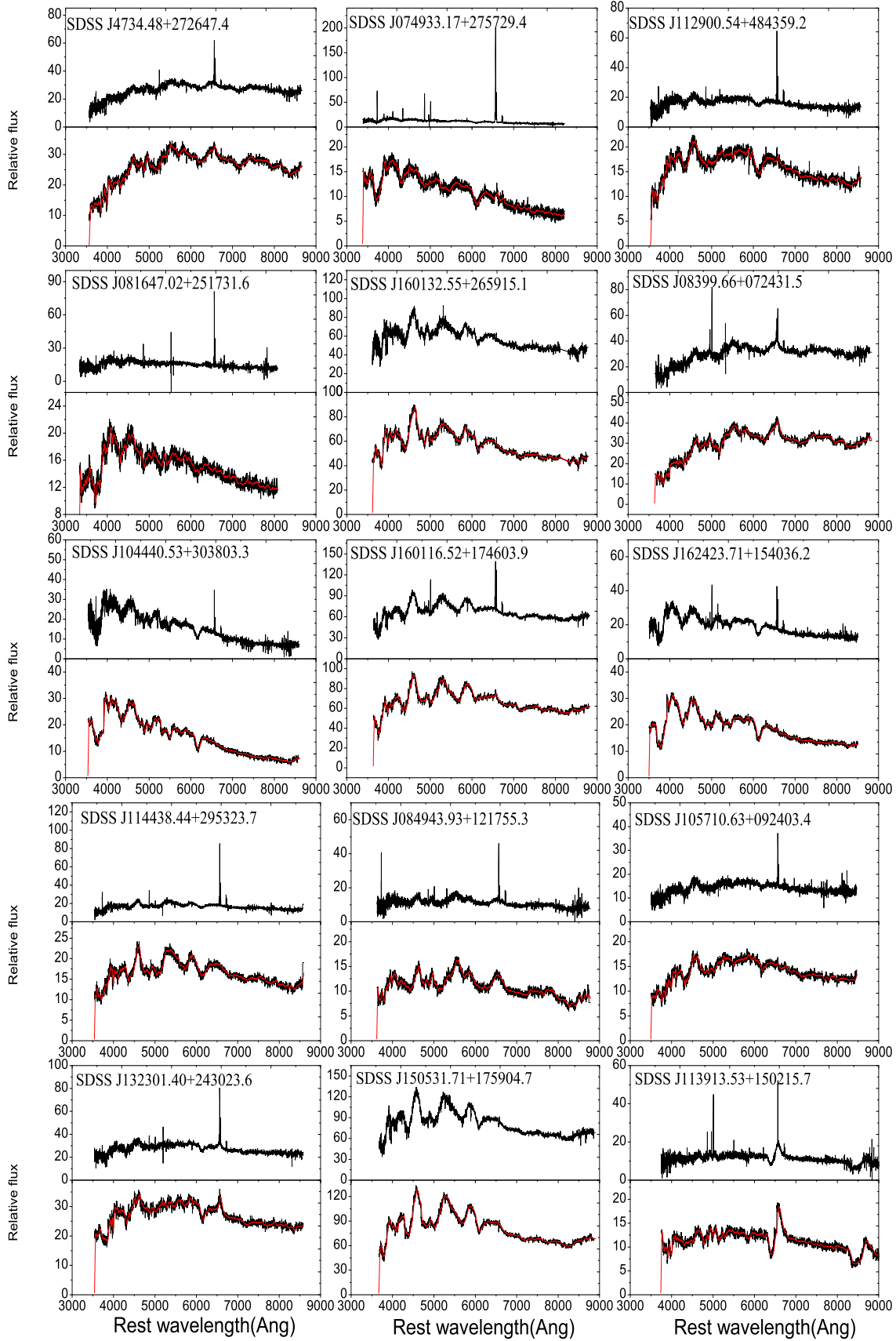


Fig.3 spectra of the new SNe identified in SDSS-DR7 are shown in each panel. In addition, the bottom plot in each panel shows the spectrum removed strong lines. The smooth spectrum is shown overplotted on this spectrum.